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NBSIR 88-3825

## Center for Electronics and Electrical Engineering

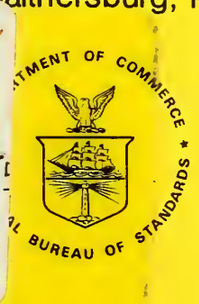
# Technical Publication Announcements

Covering Center Programs,
October to December 1987,
with 1988 CEEE Events Calendar

**15**

July 1988

U.S. Department of Commerce
National Bureau of Standards
National Engineering Laboratory
Gaithersburg, Maryland 20899

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# INTRODUCTION TO THE CEEE TECHNICAL PUBLICATION ANNOUNCEMENTS

This is the fifteenth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Publication Announcements covers the fourth quarter of calendar year 1987.

Organization of Bulletin: This issue contains citations and abstracts for Center publications published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author within each topic. Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Center conferences and workshops planned for calendar year 1988 and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U.S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. See the table of contents on the opposite page for identification of the topics covered by each program, as represented in this issue. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information.

Center sponsors: The Center Programs are sponsored by the National Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 23.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 22.

Research Information Center
National Bureau of Standards
Gaithersburg, Maryland 20899



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## SEMICONDUCTOR TECHNOLOGY

### Silicon Materials

Carver, G.P., Kang, S.S., Ehrstein, J.R., and Novotny, D.B., **Well-Defined Contacts Produce Accurate Spreading Resistance Measurements**, Journal of the Electrochemical Society, Vol. 134, No. 11, pp. 2878-2882 (November 1987).

Values of silicon resistivity calculated from spreading resistance measurements agree with values of resistivity determined from four-point probe measurements over a range of dopant density from 9 x $10^{14}$ to 2 x $10^{17}$ $cm^{-3}$. The spreading resistance resistivity values were determined solely using a mathematical expression based upon a simple geometrical model, without the need for a separate calibration. The measurements were made using aluminum-silicon contacts having a well-defined geometry. Arrays of such contacts were also used to characterize local resistivity variations. Two-contact spreading resistance measurements are shown to underestimate the amplitude of resistivity variations compared to one-contact measurements.
[Contact: Gary P. Carver, (301) 975-2091]

Polak-Dingels, P., Burdge, G., Lee, Chi H., Seabaugh, A.C., Brundage, R.T., Bell, M.I., and Albers, J., **An Investigation of Photoconductive Picosecond Microstripline Switches on Self-Implanted Silicon on Sapphire (SOS)**, Picosecond Electronics and Optoelectronics II, F.J. Leonberger, C.H. Lee, F. Capasso, and H. Morkoc, Eds. (Springer-Verlag, 1987), pp. 232-236. [Conference Proceedings of the 2d Topical Meeting on Picosecond Electronics and Optoelectronics, Incline Village, Nevada, January 14-16, 1987]

Silicon-on-sapphire (SOS) switches, damaged by implantation with 270-keV Si ions at fluence levels of $10^{12}$ to 2 x $10^{15}$ $cm^{-2}$, have been characterized by picosecond cross-correlation, Raman, and resistivity measurements. Response times as short as 9 ps were measured for an implant dose of $10^{14}$. Raman measurements indicate amorphous silicon is not formed until the dose reaches 2 x $10^{15}$ $cm^{-2}$, but there is no further decrease in response time at the higher doses. The resistivity peaks at the same dose level at which the minimum response time is observed, and then decreases for higher dose. The mobility decreases monotonically with increasing implant dose. We find the optimum implantation condition is one that produces heavy damage in the material without fully amorphizing the silicon. Amorphization decreases the on/off ratio of the device through reduction of both dark resistance and mobility, without increasing the speed of the device.
[Contact: Michael I. Bell, (301) 975-2044]

### Gallium Arsenide Materials

Forman, R.A., Hill, J.R., Bell, M.I., White, G.S., Freiman, S.W., and Ford, W., **Strain Patterns in Gallium Arsenide Wafers: Origins and Effects**, Proceedings of the International Symposium on Defect Recognition and Image Processing in III-V Compounds (DRIP 1987), Monterey, California, April 27-29, 1987, E.R. Weber, Ed. (Elsevier Science Publishers B.V., Amsterdam, 1987), pp. 63-71.

Using the rapid x-ray topographic system described earlier (in the Proceedings of DRIP I), we have examined a large number of LEC GaAs wafers, both commercial and research, and have been able to identify the sources of some of the observed patterns. We have also studied the effects of the inhomogeneous strain on the fracture properties of the wafers. The high gradients of strain cause deviations from expected crack growth behavior in fracture tests. These deviations include crack velocity variations and crack tip deflections. The grown-in defects cause point-to-point irreproducibility in hardness and toughness values for this material. Sequential wafers

Gallium Arsenide Materials (cont'd.)

exhibit closely related topographs and similar fracture properties. Inclusions have been identified in indium-doped wafers and produce a characteristic topographic pattern when the inclusion lies in the wafer under study. A characteristic strain pattern propagates away from the inclusion and produces annular rings in later wafers. The relaxation of the bow-tie strain pattern surrounding the inclusion to the annular ring pattern is likely related to the thermoelastic stress patterns described by Jordan et al.
[Contact: James R. Hill, (301) 975-2049]

Analysis Techniques

Bouldin, C.E., Forman, R.A., and Bell, M.I., **Silicon Photodiode for Fluorescence EXAFS**, Review of Scientific Instruments, Vol. 58, No. 10, pp. 1891-1894 (October 1987).

A large-area silicon diode is used as a fluorescence detector for extended x-ray absorption fine structure (EXAFS) measurements. A direct comparison of this diode detector relative to a gas ionization fluorescence detector is made. Advantages of the diode detector include: higher signal for a given photon flux (due to higher quantum efficiency), vacuum and cryogenic compatibility, freedom from microphonic noise, good linearity, extremely wide dynamic range, operation without high voltage or gas connections, very simple electronics, and low cost. A brief comparison with other detection methods for fluorescence EXAFS is given. Use of photodiodes for transmission EXAFS is discussed.
[Contact: Charles E. Bouldin, (301) 975-2046]

Dimensional Metrology

Galloway, K.F., Diehl, S.E., and Linholm, L.W., **Metrological Challenges in Semiconductor Technology: Electrical Measurements of Dimensions and Materials Properties Using Integrated Circuit Test Structures**, Proceedings of the International Conference on Semiconductor & Integrated Circuit Technology, Beijing, China, October 19-26, 1986, W. Xiuying and M. Vangxian, Eds., pp. 685-687 (World Scientific Publishers, PTE Ltd., Singapore, 1986).

The effective characterization and control of the materials, processes, devices, and circuits for very-large-scale integration (VLSI) is a major concern for semiconductor technology development. This paper reviews the types of metrological requirements associated with VLSI semiconductor technology and examines dimensional measurements and materials characterization at the wafer or chip level. Integrated circuit test structures for electrical measurements of dimensions and material properties are described.
[Contact: Loren W. Linholm, (301) 975-2052]

Nyyssonen, D., **Computer Software for the Computation of the Scattered Field and the Optical Microscope Image of Line Objects Patterned in Thick Layers**, NBSIR 87-3618 (December 1987).

This report provides computer software for calculating optical microscope images of line objects patterned in thick layers (>$\lambda$/4 thick). The algorithms used are based on a monochromatic, waveguide model which can predict the images of line objects with arbitrary edge geometry, including multilayer structures with sloped, curved, asymmetric, and undercut edges. Along with the computer software listing, the mathematics of the model, a short description of its structure and use, and test cases for help in implementation are given.
[Contact: Robert D. Larrabee, (301) 975-2298]

Dimensional Metrology (cont'd.)

Postek, M.T., **Low Accelerating Voltage Pitch Standard Based on the Modification of NBS SRM 484,** NBSIR 87-3665 (October 1987).

The National Bureau of Standards is actively developing micrometer and submicrometer standards for the scanning electron microscope (SEM). This report summarizes the progress made to extend the imaging range of the presently available SRM 484 for use as an interim standard for low-accelerating-voltage magnification calibration applications for the SEM.
[Contact: Michael T. Postek, (301) 975-2299]

Postek, M.T., **Resolution and Measurement in the Scanning Electron Microscope,** Proceedings of the 45th Annual Meeting of the Electron Microscope Society of America, G.W. Bailey, Ed., pp. 534-537 (October 1987).

The terms ultimate resolution or resolving power refer to the very best performance that can be obtained from a scanning electron microscope (SEM) given the optimum instrumental conditions and sample. However, as it relates to SEM users, the conventional definitions of this figure are ambiguous. The numbers quoted for the resolution of an instrument are not only theoretically derived, but are also verified through the direct measurement of images on micrographs. However, the samples commonly used for this purpose are specifically optimized for the measurement of instrument resolution and are most often not typical of the sample used in practical applications.
[Contact: Michael T. Postek, (301) 975-2299]

Packaging

Harman, G.G., **Acoustic Emission Test for Microelectronic Tape Automated Bonding, Acoustic Emission Thermal Shock Test for Hybrid Microcircuit Packages,** and **Designing Microelectronic Welds for Acoustic Emission Testability,** Parts 4, 5, and 9, Sec. 11, Vol. 5, Second Edition, Nondestructive Testing Handbook, P. McIntire, Ed., pp. 361 et seq. (American Society for Nondestructive Testing, 1987).

In Part 4, an acoustic-emission (AE) test method for tape automated bonding (TAB) integrity is presented, consisting of a precision testing machine that simultaneously applies a clamping force on the semiconductor chip and a lifting force on the electrical interconnecting leads. Acoustic-emission signals are transmitted through a waveguide to the detector. The system also permanently forms (raises) the leads, which is a normal requirement for TAB devices. Large acoustic-emission signals occur when a lead breaks, a bump lifts, or a weld crack propagates. Appropriate AE signal processing is also discussed.

Part 5 describes an acoustic-emission-monitored test for hybrid microcircuit package integrity which consists of a hot stage operating at 400°C, a special water-cooled acoustic-emission detector mount, and appropriate signal recording equipment. In use, the detector is coupled to the back of a hybrid package and both are set on the hot stage for approximately 30 s. Any acoustic-emission signals indicate thermal excursion damage to the glass-metal seals. The acoustic-emission signals were correlated with both room-temperature and 125°C leak tests of the packages.

Finally, in Part 9, development of tests to detect poor welds in microelectronic components is discussed. Failure modes must be understood, and this is done by understanding the characteristics of unacceptable welds.
[Contact: George G. Harman, (301) 975-2097]

Integrated Circuit Test Structures

IC Test Structures (cont'd.)

Galloway, K.F., Diehl, S.E., and Linholm, L.W., **Metrological Challenges in Semiconductor Technology: Electrical Measurements of Dimensions and Materials Properties Using Integrated Circuit Test Structures**, Proceedings of the International Conference on Semiconductor & Integrated Circuit Technology, Beijing, China, October 19-26, 1986, W. Xiuying and M. Vangxian, Eds. (World Scientific Publishers, PTE Ltd., Singapore, 1986), pp. 685-687.

The effective characterization and control of the materials, processes, devices, and circuits for very-large-scale integration (VLSI) is a major concern for semiconductor technology development. This paper reviews the types of metrological requirements associated with VLSI semiconductor technology and examines dimensional measurements and materials characterization at the wafer or chip level. Integrated circuit test structures for electrical measurements of dimensions and material properties are described.
[Contact: Loren W. Linholm, (301) 975-2052]

Schafft, H.A., **Electromigration Guidelines for $t_{50}$ Measurements**, Final Report of the 1986 Workshop on Wafer Reliability Assessment, O.D. Trapp, Ed., Lake Tahoe, California, October 19-22, 1986, pp. 149-161 (1987).

Guidelines for designing electromigration test structures and test procedures are proposed. These guidelines are intended to promote the reproducibility of electromigration characterizations of metallizations used in VLSI circuits.
[Contact: Harry A. Schafft, (301) 975-2234]

Suehle, J.S., Russell, T.J., and Galloway, K.F., **Interface Trap Effects on the Hot-Carrier-Induced Degradation of MOSFETs During Dynamic Stress**, IEEE Transactions on Nuclear Science, Vol. NS-34, No. 6, pp. 1359-1363 (1987).

Foundry and hardened n-channel MOSFETs were stressed with dynamic AC pulses and with static DC voltages. The pre-radiation hot-carrier-induced degradation is much more severe in the dynamic case than in the static case for the hardened devices. The data suggest that the pre-radiation hot-carrier degradation is strongly influenced by the relative density of interface traps and by the pulse structure. The post-radiation hot-carrier degradation is mainly influenced by the amount of radiation-induced fixed oxide charge.
[Contact: John S. Suehle, (301) 975-2247]

Device Physics and Modeling

Bennett, H.S., **Numerical Simulations on Neutron Effects on Bipolar Transistors**, IEEE Transactions on Nuclear Science, Vol. NS-34, No. 6, pp. 1372-1375 (1987).

A detailed device model that has been verified by comparisons with experimental measurements on unirradiated, state-of-the-art bipolar devices has been modified to include the effects of neutron radiation on carrier lifetimes, concentrations, and mobilities. Numerical experiments on the degradation due to neutron fluences in the dc common emitter gains for bipolar transistors with submicrometer emitter and base widths are given and compared in general terms with the few published measurements.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., and Lowney, J.R., **Physics for Models of Gallium Arsenide Devices**, Fundamental Research on the Numerical Modelling of Semiconductor Devices and Processes, J.J.H. Miller, Ed. (Boole, Dublin, 1987), pp. 31-36. [Proceedings of NUMOS 1, First International Workshop on the Numerical Model-

Device Physics & Modeling (cont'd.)

ling of Semiconductors, Los Angeles, California, December 11-12, 1986.]

Numerically simulating the behavior of GaAs devices requires a model for the distorted densities of states, band edge shifts, $\Delta E_c$ and $\Delta E_v$, and effective intrinsic carrier concentrations, $n_{ie}$. The subscripts c and v denote the conduction and valence bands, respectively. Klauder's self-energy methods (third-level and fifth-level) are applied to calculate the effects of carrier-dopant ion interactions on the densities of states for GaAs. The effects of carrier-carrier interactions have been calculated according to the theory of Abram et al. modified for 300 K. These calculations span most of the range of densities encountered in GaAs devices. This range is $5 \times 10^{16}$ $cm^{-3}$ to $10^{19}$ $cm^{-3}$ for n-type GaAs and from $10^{18}$ $cm^{-3}$ to $10^{20}$ $cm^{-3}$ for p-type GaAs. We present in this paper theoretical data on how $\Delta E_c$, $\Delta E_v$, and $n_{ie}$ vary with dopant densities. The variations with dopant and/or carrier densities of the distorted densities of states, Fermi energies screening radii, and first Born shifts will be given in a future publication.
[Contact: Herbert S. Bennett, (301) 975-2081]

Kim, J.S., **The Effect of the Gate Oxide Thickness on the Speed of MOS Integrated Circuits,** NBSIR 87-3668 (December 1987).

A simple analysis is presented for the effect of the gate oxide thickness on the circuit speed in a short-channel CMOS/inverter delay circuit. The present analysis is performed within the first-order theory of the MOS transistor. The result of the analysis shows that an optimum value of the gate oxide thickness exists, beyond which a further scaling of the gate oxide will not improve but degrade the circuit speed. The circuit speed corresponding to this optimum oxide thickness is the ultimate upper limit theoretically possible in a given MOS integrated circuit. The optimum value of the gate oxide thickness, to a first-order approximation, is proportional to the channel width W, but it is independent of the channel length L. In particular, for wide channel devices, this optimum value exceeds the 5-nm to 30-nm range, which is of practical significance in the design and processing of advanced VLSI circuits. At the optimum oxide thickness, the square-root of the net propagation delay is the sum of two components: the square-root of a purely parasitic component and the square-root of a device-dependent component.
[Contact: Jin S. Kim, (301) 975-2238]

Radiation Effects

Singh, G., Galloway, K.F., and Russell, T.J., **Temperature Induced Rebound in Power MOSFETs,** IEEE Transactions on Nuclear Science, Vol. NS-34, No. 6, pp. 1366-1369 (1987).

Enhancement mode n-channel power MOSFETs were investigated for rebound. They received 300 krad(Si) gamma dose under positive gate bias with source and drain grounded. The irradiated transistors were thermally annealed with all terminals shorted or under positive gate bias with drain and source shorted, at temperatures from 60°C to 150°C. Threshold voltage rebound was observed for some transistor types under certain experimental conditions.
[Contact: Thomas J. Russell, (301) 975-2073]

Suehle, J.S., Russell, T.J., and Galloway, K.F., **Interface Trap Effects on the Hot-Carrier-Induced Degradation of MOSFETs During Dynamic Stress,** IEEE Transactions on Nuclear Science, Vol. NS-34, No. 6, pp. 1359-1363 (1987).

Foundry and hardened n-channel MOSFETs were stressed with dynamic AC pulses and with static DC voltages. The pre-radiation hot-carrier-induced degradation is

Radiation Effects (cont'd.)

much more severe in the dynamic case than in the static case for the hardened devices. The data suggest that the pre-radiation hot-carrier degradation is strongly influenced by the relative density of interface traps and by the pulse structure. The post-radiation hot-carrier degradation is mainly influenced by the amount of radiation-induced fixed oxide charge.
[Contact: John S. Suehle, (301) 975-2247]

Insulators and Interfaces

Baghdadi, A., and Walters, E.J., **Semiconductor Measurement Technology: Silicon-on-Insulator: A Categorized Bibliography Including Abstracts**, NBS Special Publication 400-80 (December 1987).

This bibliography of silicon-on-insulator SOI technology was compiled from a literature search of three data bases; INSPEC, Engineering Index, and Chemical Abstracts. The bibliography has been categorized according to the technique used to produce the SOI substrate. It includes the abstracts for most of the papers. It can either be used to obtain a quick evaluation of the "state of the art" in a particular SOI technique, or as a guide for further in-depth study.
[Contact: Aslan Baghdadi, (301) 975-2062]

Photodiodes

Korde, R., and Geist, J., **Quantum Efficiency Stability of Photodiodes**, Applied Optics, Vol. 26, pp. 5284-5290 (1987).

The stability of the quantum efficiency of inversion layer, phosphorus-diffused (n-conductivity type on p) and boron-diffused (p on n) photodiodes has been investigated. Unsatisfactory silicon-silicon dioxide interfaces, latent recombination centers in the diffused layers, and moisture absorption by the device were identified as possible causes of instability. Diodes were fabricated using processes in which these sources of instability were carefully controlled. The resulting diodes were subjected to various accelerated aging tests, and the external quantum efficiency of the diodes was monitored during the tests. Diodes made by older procedures, in which some important parameters affecting stability were not controlled, were included in the study for comparison. The major result of this work is the demonstration that n on p photodiodes are inherently more stable than p on n types in the ultraviolet and blue spectral regions, but that stable p on n devices can also be produced with sufficient care.
[Contact: Jon Geist, (301) 975-2066]

Other Semiconductor Metrology Topics

Scace, R.I., **ASTM and SEMI Standards for the Semiconductor Industry**, Emerging Semiconductor Technology, Vol. ASTM STP-960, D.C. Gupta and P.H. Langer, Eds., pp. 15-18 (1987).

This article, based on an introductory talk at the symposium, points out the needs for standards in the semiconductor industry and briefly describes the activities of the organizations that develop them. The direct cooperation between the several organizations in the world active in semiconductor standards development is briefly described. Readers are invited to join these development activities.
[Contact: Robert I. Scace, (301) 975-2220]

## FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Laug, O.B., **A Precision Power Amplifier for Power/Energy Calibration Applications**, IEEE Transactions on Instrument and Measurement, Vol. IM-36,

Waveform Metrology (cont'd.)

No. 4, pp. 994-1000 (December 1987). [Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 129-134.]

A precision power amplifier for use in power/energy calibration applications is described. The amplifier was primarily designed to boost the output amplitude of a digital generator to provide the nominal 120- or 240-root-mean-square (rms) voltage component of a "phantom" calibration power source. The amplifier has a fixed gain of 40 and can provide a maximum output voltage swing of 970 V peak-to-peak or 340-V rms at 100-mA rms. The bandwidth is from dc to 150 kHz, and at 60 Hz the observed no-load short-term amplitude and phase instabilities are ±5 ppm and ±5 μrad, respectively. The amplifier design uses high-voltage n-channel MOSFETs in the output driver stage together with a unique circuit topology of opto-isolators between the low-level input stage and the high-level output stage.
[Contact: Owen B. Laug, (301) 975-2412]

Nahman, N.S., **Software Correction of Measured Pulse Data**, Fast Electrical and Optical Measurements, Vol. 1, J.E. Thompson and L.H. Luessen, Eds. (Martinus Nijhoff, Dordrecht, 1986), pp. 351-417.

The fundamental concern in the software correction of measured pulse waveform data is the solution of an ill-posed deconvolution problem which arises when one (or both) of the known waveforms is (are) corrupted by errors due to interference, noise, instrumentation drift, etc. The variables concerned are related to each other by the convolution integral. When one of the integrand functions is unknown while the other two functions are known, the convolution equation becomes an integral equation for the unknown waveform. Solution of an ill-posed deconvolution problem is obtained by signal processing or filtering and at most yields an estimate for the unknown waveform. The objective of this discussion is to bring out the ideas of ill-posedness and to give examples of applications to pulse measurement problems which require deconvolution, i.e., the removal (correction) of pulse source effects and/or measurement system effects as encountered in signal pulse waveform measurements and system impulse response measurements.
[Contact: William L. Gans, (303) 497-3538]

Oldham, N.M., Parker, M.E., Young, A., and Smith, A.G., **A High-Accuracy, 10 Hz-1 MHz Automatic AC Voltage Calibration System**, IEEE Transactions on Instrument and Measurement, Vol. IM-36, No. 4, pp. 883-887 (December 1987). [Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 279-281.]

An automatic system for calibrating high-accuracy ac voltmeters and calibrators is described. The system is based on traditional coaxial thermal voltage converters to provide ac voltage measurement uncertainties of 5 to 20 ppm in the audiofrequency range and 5 to 250 ppm over the full range from 10 Hz to 1 MHz at voltages between 0.5 to 600 V. Lower levels (0.01 to 0.5 V) are realized using wideband inductive dividers. Specialized hardware and measurement techniques make it possible to achieve these uncertainties in test periods of approximately 1 min. Random errors introduced by the measurement system are typically less than 2 ppm (one standard deviation).
[Contact: N. Michael Oldham, (301) 975-2408]

Souders, T.M., Schoenwetter, H.K., and Hetrick, P.S., **Characterization of a Sampling Voltage Tracker for Measuring Fast, Repetitive Signals**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 4, pp. 956-960 (December 1987). [Proceedings of the

Waveform Metrology (cont'd.)

IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 240-243.]

An equivalent-time sampling and digitizing system is described, together with test methods for characterizing its dynamic performance. Time-base errors, linearity errors, step response parameters, harmonic distortion, and frequency response are considered, and typical measurement results are included. The system is capable of state-of-the-art measurements for signal frequencies up to 200 MHz.
[Contact: T. Michael Souders, (301) 975-2406]

Stenbakken, G.N., **Characterizing Square and Triangular Waveforms**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 4, pp. 961-963 (December 1987). [Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 9-11.]

A method has been developed for determining the parameters and errors of square and triangular waveforms relative to idealized waveforms, even when the waveforms are highly distorted. The method is based on measurements obtained by sampling the waveform. An idealized waveform is fitted to these sampled data using a least-squared error algorithm. The errors in the waveform are defined as the deviations between the data samples and the ideal waveform. Also, the parameters of the measured waveform are defined as the corresponding parameters of the fitted ideal waveform.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

Turgel, R.S., and Vecchia, D.F., **Precision Calibration of Phase Meters**, IEEE Transactions on Instrumentation & Measurement, Vol. IM-36, No. 4, pp. 918-922 (December 1987). [Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 135-137.]

Using the calibration of a phase meter with a nominally linear response as an example, a statistical approach is discussed for predicting worst-case offsets of the meter response characteristic from the value of the reference standard. A linear calibration curve is used to model the meter response, and statistical tests are described which test the appropriateness of the model and whether the calculated calibration curve differs significantly from the ideal. Various levels of corrections to be applied can then be determined on the basis of these tests, and limits to offsets are calculated for each of the levels. By extending this approach, it is possible to predict limits of uncertainty when using the calibrated meter to make measurements.
[Contact: Raymond S. Turgel, (301) 975-2420]

Cryoelectronic Metrology

Kautz, R.L., **Activation Energy for Thermally Induced Escape from a Basin of Attraction**, Physics Letters A, Vol. 125, No. 6,7, pp. 315-319 (November 23, 1987).

In the limit of low temperature, the most probable path for escape from a basin of attraction is the path which minimizes the available thermal noise energy required for escape. This minimum energy is the activation energy of escape.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Kautz, R.L., and Lloyd, F.L., **Precision of Series-Array Josephson Voltage Standards**, Appl. Phys. Lett. Vol. 51, No. 24, pp. 2043-2045 (December 1987).

Cryoelectronic Metrology (cont'd.)

Comparison of two series-array Josephson voltage standards operated at over 1 V shows that they differ in voltage by less than two parts in $10^{17}$.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Lloyd, F.L., Hamilton, C.A., Beall, J.A., Go, D., Ono, R.H., and Harris, R.E., **A Josephson Array Voltage Standard at 10 Volts**, IEEE Electron Device Letters, Vol. EDL-8, No. 10, pp. 449-450 (October 1987).

The technology of Josephson voltage standards has been extended to an array of 14,184 junctions which is capable of generating over 150,000 quantized voltage levels spanning the range from -12 to +12 V. This makes possible the direct calibration of 10-V zener reference standards without the use of a voltage divider.
[Contact: Frances L. Lloyd, (303) 497-3254/3988]

Antenna Metrology

Francis, M.H., and Hill, D.A., **Out-of-Band Response of Array Antennas**, Proceedings of the 9th Annual Meeting and Symposium of the Antenna Measurement Technique Association (AMTA), Seattle, Washington, September 28-October 2, 1987, pp. 14-19 (1987).

At the National Bureau of Standards, we have examined the out-of-band response of array antennas from both a theoretical and experimental point of view. Theory shows that the out-of-band response of an antenna depends primarily on two factors: the antenna's input impedance and its directivity. Experiment shows that, for most practical purposes, the out-of-band response of an antenna can be estimated from a measurement of the antenna's input reflection coefficient alone. If the reflection coefficient is low, the antenna response will be good; if the reflection coefficient is high, the antenna response will be poor.
[Contact: Michael H. Francis, (303) 497-5873]

Hill, D.A., and Francis, M.H., **Out-of-Band Response of Antenna Arrays**, Proceedings of the 1987 IEEE International Symposium on Electromagnetic Compatibility, Symposium Record, August 25-27, 1987, Atlanta, Georgia, pp. 435-438. [An expanded version appeared as NBSIR 86-2037 (June 1986).]

The response of antenna arrays to out-of-band frequencies has been analyzed using the effective aperture approach. An average value of effective aperture can be obtained by averaging the incidence angle and the polarization of the incident field. Far-field patterns have also been calculated by treating the array element excitations as random variables. The randomness in the element excitations causes a decrease in directivity and an increase in sidelobe level.
[Contact: David A. Hill, (303) 497-3472]

Koepke, G.H., Hill, D.A., and Ma, M.T., **Analysis of an Array of Log-Periodic Dipole Antennas for Generating Test Fields**, NBSIR 87-3068 (June 1987).

An analysis of log-periodic dipole antennas was extended to study their use in arrays designed for electromagnetic susceptibility measurements. Parameters of an array of five log-periodic dipole antennas were calculated and in some cases compared to a single log-periodic dipole antenna. These parameters were used to evaluate the tradeoffs that exist in the design of an optimum transmitting antenna for susceptibility measurements.
[Contact: Galen H. Koepke, (303) 497-5766]

Muth, L.A., **Experimental Study of Interpanel Interactions at 3.3 GHz**, Proceedings of the 9th Annual Meeting and Symposium of the Antenna Measure-

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ment Technique Association (AMTA), Seattle, Washington, September 28-October 2, 1987, pp. 25-29 (1987).

A general theoretical approach is formulated to describe the complex electromagnetic environment of an N-element array. The theory reveals the element-to-element interactions and multiple reflections within the array. To experimentally verify some features of the theory, measurements on experimental array panels in various configurations were made. These array panels consisted of 256 microstrip radiating elements. In each of the configurations, both the near-field and portside signals were measured to study the interactions between these panels. In particular, the effects of open-circuited array panels on the radiation pattern of a single panel are observed both in the near field and in the far field. It is found that internal scattering is the main mechanism of interaction between panels, rather than reradiation of signals received from adjacent panels. The effects of scattering are observable at the -50 dB level.
[Contact: Lorant A. Muth, (303) 497-3603]

Noise Metrology

Daywitt, W.C., **Horn Design Equations for the NBS Horn-Type Noise Standards**, NBSIR 87-3073 (August 1987).

Equations are given for calculating the interior dimensions of the horn pickup in the NBS millimeter-wave noise standards. These dimensions ensure negligible internal horn reflections, resulting in an accurate calculation of the horn attenuation. Measurements in the WR10 horn show a reflection of magnitude less than 0.001.
[Contact: William C. Daywitt, (303) 497-3720]

Microwave and Millimeter-Wave Metrology

Clague, F.R., and Larsen, N.T., **A Transient Response Error in Microwave Power Meters Using Thermistor Detectors**, 28th ARFTG (Automatic RF Techniques Group) Conference Digest, Saint Petersburg Beach, Florida, December 4-5, 1986, pp. 79-89 (April 1987).

Broadband coaxial thermistor mounts are commonly used in automated precision microwave measurement systems such as six-port networks. To reduce the effect of temperature drift and to decrease the total measurement time, it is desirable to measure the dc bias voltage on the thermistor mount very quickly after turning the radio frequency on or off. However, investigation has revealed that a coaxial mount may take much longer to settle to a stable dc bias voltage than the thermistor element time constant or the associated power meter servo bandwidth would indicate. If the bias voltage is measured before this transient ends, the error in the calculated rf power can be very large; as much as 1.4 percent has been observed. This paper describes these transients and gives measured durations and maximum error for a number of different bolometer mounts.
[Contact: Fred B. Clague, (303) 497-5778]

Daywitt, W.C., **A Simple Technique for Determining Joint Losses on a Coaxial Line from Swept-Frequency Reflection Data**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 468-473 (June 1987). [Abbreviated version published in CPEM (Conference on Precision Electromagnetic Measurements) Digest, p. 40 (June 23-27, 1986, NBS Gaithersburg, R.F. Dziuba, Ed.)]

A need to separate connector loss from swept-frequency automatic network analyzer measurements to check an attenuation calculation for a low-loss, coaxial line has led to a simple graphical technique for determining joint losses. Measurements show that in addition to the connector loss, it is also possible

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to determine joint losses around center conductor bead supports on the line itself. Preliminary results indicate that losses in the millidecibel range can be determined to a precision of a few tenths of a millidecibel or better, even though the data are obscured by considerable connector loss and calibration error. Results were checked by independent measurements and show excellent agreement.
[Contact: William C. Daywitt, (303) 497-3720]

Daywitt, W.C., **A Simple Technique for Investigating Defects in Coaxial Connectors**, IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-35, No. 4, pp. 460-464 (April 1987).

This paper describes a technique that uses swept-frequency automatic network analyzer (ANA) data for investigating electrical defects in coaxial connectors. The technique will be useful to connector and ANA manufacturers and to engineers interested in determining connector characteristics for error analyses. A simplified theory is presented and the technique illustrated by applying it to perturbations caused by the center conductor gap in a 7-mm connector pair.
[Contact: William C. Daywitt, (303) 497-3720]

Engen, G.F., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Background and Theory**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 501-506 (June 1987). [Abbreviated version published in CPEM (Conference on Precision Electrical Measurements) Digest, p. 236 (June 23-27, 1986, NBS Gaithersburg, R.F. Dziuba, Ed.)]

One of the major challenges confronting the microwave metrologist today is that of providing an accuracy assessment for the automatic network analyzer (ANA). This paper provides the background and theory for the recently developed on-line solution now in use with the six-port systems at the National Bureau of Standards.
[Contact: Cletus A. Hoer, (303) 497-3705]

Hoer, C.A., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Treatment of Systematic Errors**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 514-519 (June 1987).

Expressions are derived for calculating estimates of the systematic errors in dual six-port or four-port measurements of reflection coefficient and scattering parameters due to imperfections in the transmission-line standard used to calibrate the system. A new mathematical model for a four-port reflectometer makes it easier to visualize and analyze these errors. In this new model, two of the three parameters needed to characterize a four-port can be determined without standards. All imperfections in the standard perturb only the third parameter which acts as an impedance transformer.
[Contact: Cletus A. Hoer, (303) 497-3705]

Hoer, C.A., **Some Questions and Answers Concerning Air Lines as Impedance Standards**, 29th ARFTG (Automatic RF Techniques Group) Conference Digest, Las Vegas, Nevada, June 12-13, 1987, pp. 161-173 (1987).

This paper attempts to answer a number of questions that arise when using one or more lengths of precision coaxial transmission line to calibrate a dual six-port automatic network analyzer, questions such as: How important is the quality of the test port relative to that of the line? What type connectors should the line standards have? What are the advantages of using two lines instead of one line and a through connection when test port imperfections are

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considered? How many lines are optimum from a quality control point of view? What should the lengths be? The answers to these questions appear to be:

- The quality of the line is much more important than that of the test port. A perfect line will calibrate out most imperfections in the test port. An example is given where 75-Ω test ports are calibrated with 50-Ω lines, and then used to measure reflection coefficient relative to 50 Ω with very little error.
- Greatest accuracy is achieved with line standards having male connectors.
- Two lines get rid of many test port imperfections that one line cannot. Three lines will show up a problem if one line is bad. Five lines will identify which line is bad. Five is probably optimum.
- There may not be an optimum for the actual lengths of a set of lines, but there does appear to be an optimum difference in the lengths.

[Contact: Cletus A. Hoer, (303) 497-3705]

Hoer, C.A., and Engen, G.F., **Calibrating a Dual Six-Port or Four-Port for Measuring Two-Ports with Any Connectors**, Proceedings of the IEEE-MTT Symposium, Baltimore, Maryland, June 2-4, 1986, pp. 665-668 (1986).

A technique is described for calibrating a dual six-port or four-port ANA so that the scattering parameters of two-port devices having any combination of connectors can be measured. The technique is a generalization of the "thru-reflect-line" calibration technique in which the "thru" is replaced with a second length of precision transmission line.

[Contact: Cletus A. Hoer, (303) 497-3705]

Hoer, C.A., and Engen, G.F., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Extension to Nonmating Connectors**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 524-529 (June 1987). [Abbreviated version published in CPEM (Conference on Precision Electrical Measurements) Digest, pp. 241-242 (June 23-27, 1986, NBS Gaithersburg, R.F. Dziuba, Ed.)]

A technique is described for calibrating a dual six-port or four-port automatic network analyzer (ANA) so that the scattering parameters of two-port devices having any combination of connectors can be measured. The technique is a generalization of the "thru-reflect-line" calibration technique in which the "thru" is replaced with a second length of precision transmission line. Expressions for errors associated with the second line are derived.

[Contact: Cletus A. Hoer, (303) 497-3705]

Judish, R.M., and Engen, G.F., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Statistical Methods for Random Errors**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 507-513 (June 1987). [Abbreviated version published in CPEM (Conference on Precision Electrical Measurements) Digest, p. 237 (June 23-27, 1986, NBS Gaithersburg, R.F. Dziuba, Ed.)]

A basic property of a measurement process is that repeated observations of the same quantity will not give identical results due to the presence of random errors. In order to assess the effects of random errors in our measurement process, we need to build in redundancy. This paper presents a brief summary of the statistical methods used to evaluate the random errors in dual six-port measurements of reflection coefficient and scattering parameters.

[Contact: Robert M. Judish, (303) 497-3380]

Juroshek, J.R., **On-Line Accuracy Assessment for the Dual Six-Port ANA:**

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**Experimental Results**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 520-523 (June 1987). [Abbreviated version published in CPEM (Conference on Precision Electrical Measurements) Digest, p. 240 (June 23-27, 1986, NBS Gaithersburg, R.F. Dziuba, Ed.)]

When a calibration laboratory such as the National Bureau of Standards (NBS) performs a measurement for a customer, the accuracy which the laboratory attaches to its measurements is a significant part of the customer's report. In some instances, the accuracy statement may be more important to the customer than the measurement itself. Modern automated measurement systems can often perform hundreds of measurements in a fraction of a second. However, few, if any, of these systems attempt to assess the accuracy of those measurements in a real-time or on-line basis.

The accuracy of a modern automatic network analyzer (ANA) is a function of a number of variables. Connector quality, operator technique, system hardware, and system calibration are just a few of the many parameters that affect the day-to-day accuracy of an automated system. This paper describes the results of the current efforts at NBS to implement on-line accuracy estimates for its dual six-port network analyzers. Results are presented showing uncertainty estimates obtained in quasi-real time during the measurement of customers' devices.
[Contact: John R. Juroshek, (303) 497-5362]

Juroshek, J.R., **A Study Into Measurements of Connector Repeatability Using Highly Reflecting Loads**, IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-35, No. 4, pp. 457-460 (April 1987).

This paper investigates the repeatability of measurements of the reflection coefficient $\Gamma$ of highly reflecting devices with changes in the RF connector joint. The changes in the connector joint are due to disconnecting and reconnecting the connector pair. It is shown that many of the measurement discrepancies observed in practice can be explained with a simple connector model. The paper shows that the sensitivity of measuring RF connector changes can be increased by using highly reflecting loads. The changes in $\Gamma$ due to changes in resistance or reactance can be four times greater for highly reflecting devices $(|\Gamma| \approx 1)$ than for nonreflecting devices $(|\Gamma| \approx 0)$. Experiments on two devices with 14-mm connectors are described in order to compare them with theory. The basic principles described in this paper should be beneficial to connector designers who need to observe small changes in connector parameters and to the work of calibration standards designers, where small connector imperfections are a major part of their measurement uncertainty.
[Contact: John R. Juroshek, (303) 497-5362]

Saulsbery, L.F., and Adair, R.T., **ANA Measurement Results on the ARFTG Traveling Experiment**, 28th ARFTG (Automatic RF Techniques Group) Conference Digest, Saint Petersburg Beach, Florida, December 4-5, 1986, pp. 65-78 (April 1987).

The Automatic RF Techniques Group (ARFTG) Executive Committee has assembled two traveling measurement assessment kits. Each of these kits consists of: 1-dB, 20-dB, 40-dB, and 60-dB attenuators; a 50-Ω termination; a 10-cm air line; 1.2-V standing-wave ratio and 2.0-V standing-wave ratio mismatched terminations; and a short-circuit termination. These devices are equipped with precision 7-mm coaxial connectors. The traveling kits are being circulated among measurement laboratories who wish to assess their ability to measure reflection coefficient, attenuation, and phase shift from 300

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MHz to 17 GHz. The results obtained on ten different automated measurement systems are presented.
[Contact: Cletus A. Hoer, (303) 497-3705]

Electro-Optic Metrology

Polak-Dingels, P., Burdge, G., Lee, Chi H., Seabaugh, A.C., Brundage, R.T., Bell, M.I., and Albers, J., **An Investigation of Photoconductive Picosecond Microstripline Switches on Self-Implanted Silicon on Sapphire (SOS)**, Picosecond Electronics and Optoelectronics II, F.J. Leonberger, C.H. Lee, F. Capasso, and H. Morkoc, Eds. (Springer-Verlag, 1987), pp. 232-236. [Conference Proceedings of the 2d Topical Meeting on Picosecond Electronics and Optoelectronics, Incline Village, Nevada, January 14-16, 1987]

Silicon-on-sapphire (SOS) switches, damaged by implantation with 270-keV Si ions at fluence levels of $10^{12}$ to 2 × $10^{15}$ $cm^{-2}$, have been characterized by picosecond cross-correlation, Raman, and resistivity measurements. Response times as short as 9 ps were measured for an implant dose of $10^{14}$. Raman measurements indicate amorphous silicon is not formed until the dose reaches 2 × $10^{15}$ $cm^{-2}$, but there is no further decrease in response time at the higher doses. The resistivity peaks at the same dose level at which the minimum response time is observed, and then decreases for higher dose. The mobility decreases monotonically with increasing implant dose. We find the optimum implantation condition is one that produces heavy damage in the material without fully amorphizing the silicon. Amorphization decreases the on/off ratio of the device through reduction of both dark resistance and mobility, without increasing the speed of the device.
[Contact: Michael I. Bell, (301) 975-2044]

Other Fast Signal Topics

Hill, D.A., and Cavcey, K.H., **Coupling Between Two Antennas Separated by a Planar Interface**, IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-25, No. 4, pp. 422-431 (July 1987).

The plane-wave spectrum technique is used to analyze the coupling between a pair of antennas separated by a planar interface. Multiple reflections between the antennas or between either antenna and the interface are included in the formulation. The formulation is used for model detection of buried objects, and a low-frequency metal detector example is analyzed in detail. For a transmitting loop and a buried oblate spheroid, the plane-wave spectrum technique is shown to agree with well-known quasi-static approximations. Some experimental results from a 3-kHz metal detector are also shown.
[Contact: David A. Hill, (303) 497-3472]

**ELECTRICAL SYSTEMS**

Power Systems Metrology

Kelley, E.F., and Hebner, R.E., **Electro-Optic Field Measurement at a Needle Tip and Streamer Initiation in Nitrobenzene**, 1986 Annual Report of the Conference on Electrical Insulation and Dielectric Phenomena, Claymont, Delaware, November 2-6, 1986, pp. 272-277 (October 1987).

Kerr-effect electro-optic observations of the impulse field are made in the vicinity of the tip of a needle-sphere electrode geometry. Distortions from the Laplacian field indicate charge injection from the tip along a narrow channel prior to streamer initiation. Charge densities estimated to be on the order of 100 $\mu C/cm^3$ exist in the channel. An order of magnitude calculation suggests that sufficient energy is deposited in the channel to cause vaporization of the liquid due to joule heat-

Power Systems Metrology (cont'd.)

ing. The streamer will initiate where the charge injection channel touches the electrode.
[Contact: Edward F. Kelley, (301) 975-2424]

Kelley, E.F., Nehmadi, M., Hebner, R.E., McKenny, P.J., and Forster, E.O., **Simultaneous Measurement of Light Emission, Current Pulses and Growth of Prebreakdown Streamers in Hexane,** Proceedings of the 1987 Conference on Electrical Insulation and Dielectric Phenomena, Gaithersburg, Maryland, October 19-22, 1987, pp. 132-137 (October 1987).

High-speed, image-converter photography is used to document the growth characteristics of prebreakdown phenomena emanating from a cathode needle in a needle-sphere electrode system placed in a liquid. The cathode streamer growth characteristics are compared to the pulsed nature of the current feeding the streamer and light emission from the streamer. The fact that there is a strong temporal correlation between the current and light pulses is confirmed. However, it is found that no strong correlation exists between this pulse-like behavior and the growth of the prebreakdown event, and that the streamer grows rather uniformly despite the discrete nature of the current supplied. This information should contribute to the development of theoretical modeling efforts on the generation and development of prebreakdown phenomena in liquids.
[Contact: Edward F. Kelley, (301) 975-2424]

McKnight, R.H., **Measurement of Electric Field and Ion-Related Quantities, Air Ions: Physical and Biological Aspects,** Chapter 3, J.M. Charry and R.I. Kavet, Eds., pp. 23-55 (CRC Press, Inc., Boca Raton, Florida, 1987).

Measurements of various quantities to describe the electrical characteristics of the atmosphere have been made for many decades by atmospheric scientists using a variety of instruments and measurement techniques. The purpose of this chapter is to describe those techniques which have application in present-day ion-related research. Topics covered include definitions of terms; measurements of electric field, space potential, vertical current density, conductivity, net space-charge density, unipolar ion density, and ion mobility; species identification; errors associated with external electric fields and off-ground operation of instruments; and applications of measurements (23 figures, 101 literature references).
[Contact: Ronald H. McKnight, (301) 975-2431]

McKnight, R.H., **Operation of an Ion Counter in the Ground Plane Under a Monopolar High-Voltage Line,** Proceedings of the Twenty-Third Hanford Life Sciences Symposium, Interaction of Biological Systems with Static and ELF Electric and Magnetic Fields, Richland, Washington, October 2-4, 1984, pp. 1-7 (1987).

Studies have been made of the operation of an ion counter with the inlet located in the ground plane near a monopolar high-voltage line. Electric-field values at the ground plane ranged between 14.8 kV/m and 29.8 kV/m, while ion current densities varied from 0.1 to 0.43 $\mu A/m^2$. An observed variation in measured ion density with volumetric flow rate through the counter appears to be primarily due to losses in the duct between the ground-plane opening and the ion-counter inlet.
[Contact: Ronald H. McKnight, (301) 975-2431]

Van Brunt, R.J., Herron, J.T., and Fenimore, C., **Corona-Induced Decomposition of Dielectric Gases,** Gaseous Dielectrics V, Proceedings of the Fifth International Symposium on Gaseous Dielectrics, Knoxville, Tennessee, May 3-7, 1987 (Pergamon Press, New York,

Power Systems Metrology (cont'd.)

1987), pp. 163-173.

A three-zone model for chemical decomposition of electronegative gases in negative point-plane corona discharges is proposed which considers the discharge glow, ion-drift, and main gas volumes respectively as separate regions of diminishing chemical activity and increasing relative size. The proposed model is shown to be useful in predicting discharge by-product yields and the dependences of these yields on discharge current and gas mixture composition. As an example, the model is applied here to the decomposition of pressurized $SF_6$ containing trace levels of water vapor and is shown to yield results for oxyfluoride production that are in satisfactory agreement with observations.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Superconductors

Ekin, J.W., **Irregularity in Nb-Ti Filament Area and Electric Field Versus Current Characteristics**, Cryogenics, Vol. 27, pp. 603-607 (November 1987).

There is a correlation between irregularity in filament area ("sausaging") and the shape of a superconductor's electric field (E) versus current (I) relationship. The shape of the E-I characteristic is quantified in terms of the resistive transition parameter, n, defined by $E \propto I^n$. Low values of n less than about 20 correlate with a wide filament diameter distribution, while n values over 50 correspond to a distribution more than 2.5 times smaller. It is proposed that the low-field (constant) value of n be used as an index of filament quality in evaluating different superconductors for practical applications. A model is also suggested to explain this effect in terms of a locally depressed filament critical current, which forces current to transfer across the normal matrix material into neighboring filaments. The relationship between n and the statistical distribution of filament diameters may be useful in that it permits an easy method of estimating the extent of sausaging in practical multifilamentary Nb-Ti superconductors from measurements of n.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J.W., **Transport Critical Currents in Bulk Sintered $Y_1Ba_2Cu_3O_x$ and Possibilities for Its Enhancement**, Advanced Ceramic Materials, Vol. 2, Special Issue 3B, pp. 586-591 (1987).

Several general processing methods for increasing the critical current density, $J_c$, in bulk sintered $Y_1Ba_2Cu_3O_x$ superconductor are outlined. Data indicate that the transport $J_c$ in bulk polycrystalline specimens is dominated by a weak-link region between high-$J_c$ grains and that potentially much higher $J_c$ may be possible. Two possible causes of such a weak-link phenomenon are considered: low $T_c$ phases or impurities localized in the grain boundary region, and anisotropy of the superconducting properties. Several methods for minimizing the weak-link effects to increase the $J_c$ are discussed.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J.W., Braginski, A.I., Panson, A.J., Janocko, M.A., Capone, D.W., Zaluzec, N.J., Flandermeyer, B., deLima, O.F., Hong, M., Kwo, J., and Liou, S.H., **Evidence for Weak Link and Anisotropy Limitations on the Transport Critical Current in Bulk Polycrystalline $Y_1Ba_2Cu_3O_x$**, Journal of Applied Physics, Vol. 62, No. 12, pp. 4821-4828 (15 December 1987).

Measurements of the transport critical-current ($J_c$), magnetization Jc, and magnetoresistance in a number of bulk sintered samples of $Y_1Ba_2Cu_3O_x$ from several different laboratories indicate that the transport $J_c$ is limited by weak-link regions between high $J_c$

Superconductors (cont'd.)

regions. The weak-link $J_c$ has a Josephson character, decreasing by two orders of magnitude as the magnetic field is increased from 0.1 to 10 mT at 77 K. An examination of the grain-boundary region in $Y_1Ba_2Cu_3O_x$ shows no observable impurities or second phases to the scale of the [001] lattice planes (~12 Å). The effect of intrinsic conduction anisotropy is discussed. A current-transfer model is proposed in which weak conduction along the c-axis plays a role in limiting $J_c$ at grain boundaries. Orienting the grains in the powder state during processing may result in enhanced transport $J_c$ in bulk conductors.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J.W., Panson, A.J., Braginski, A.I., Janocko, M.A., Hong, M., Kwo, J., Liou, S.H., Capone, D.W., and Flandermeyer, B., **Transport Critical-Current Characteristics of $Y_1Ba_2Cu_3O_x$**, Proceedings of Symposium S 1987 Spring Meeting of the Materials Research Society, Anaheim, California, April 23-24, 1987, D.U. Gubser and M. Schluter, Eds., pp. 223-226 (1987).

Voltage vs. current (V-I) characteristics were measured at magnetic fields up to 24 T at a temperature of 77 K in several $Y_1Ba_2Cu_3O_x$ samples fabricated at different laboratories. Critical temperatures, $T_c$, measured by resistivity were about 93 K. All samples showed linear V-I characteristics at current levels much greater than the critical current, $I_c$. However, the slope was significantly less than the normal resistance at $T_c$. The slope increased with magnetic field and reached the normal resistance value only at fields greater than 24 T. Values of the transport critical-current density $J_c$ near zero magnetic field were generally low and variable (about 1 to 200 A/cm$^2$). The transport $J_c$ fell sharply when magnetic field was applied, decreasing by about an order of magnitude between $10^{-3}$ T and 1 T. This leads to an effective upper critical field for transport critical currents in $Y_1Ba_2Cu_3O_x$ that is significantly less than the upper critical field defined by the field at which the resistance increases to the normal-state value. The transport $J_c$ appears to be significantly less than $J_c$ calculated from magnetization data on similar samples. These results are consistent with the transport critical-current in the $Y_1Ba_2Cu_3O_x$ system being dominated by a "weak-link" region between high-$J_c$ grains.
[Contact: John W. Ekin, (303) 497-5448]

Goodrich, L.F., Pittman, E.S., and Ekin, J.W., **Studies of NbTi Strands Extracted from Coreless Rutherford Cables**, IEEE Transactions on Magnetics, Vol. MAG-23, No. 2, pp. 1642-1645 (March 1987).

The electromechanical properties of NbTi strands extracted from coreless Rutherford cables were studied to clarify the relative effects of strand location and field angle on current degradation that occurs in cables that have been compacted into a keystone shape. Detailed critical-current measurements were made on two samples which were fabricated under controlled conditions. These are prototype cables for high-energy physics applications. Specific factors that are addressed are the nature, location, and amount of degradation. This information is intended to lead to methods for reducing the amount of critical-current degradation in cable manufacture.
[Contact: Loren F. Goodrich, (303) 497-3143]

## ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

Crawford, M.L., **A TEM Driven Reverberating Chamber: A Single Facility for Radiated EMS/V Testing, 10 kHz - 18 GHz?**, Proceedings of the 1987 International Conference on Electromagnetic Compatibility (EMC EXPO), San Diego, California, May 19-21, 1987, pp.

Radiated EMI (cont'd.)

T11.18-T11.28.

This paper discusses the design, operation, and evaluation of a reverberating chamber, excited by a transverse electromagnetic (TEM) transmission line, for use in establishing radiated electromagnetic fields for susceptibility/vulnerability (EMS/V) testing of electronic equipment. The potential range of application is from 10 kHz to 18 GHz. Included are brief descriptions of the facility, the operation procedures, the method for determining the test field amplitude inside the chamber, and the evaluation of the chamber's electrical parameters such as VSWR and E-field strength as a function of input power. Also presented are the E-field spatial uniformity and a summary of measurement uncertainties and conclusions derived from the test results.
[Contact: Myron L. Crawford, (303) 497-5497]

Crawford, M.L., and Bean, J.L., **NSWC Reverberating Chamber-A High Power Microwave Exposure Chamber**, Proceedings of the Third National High Power Microwave Technical Conference, Kirtland Air Force Base, New Mexico, December 1-5, 1986, unpaged (1987). [An expanded version appeared under the title "Electromagnetic Radiation Test Facilities Evaluation of Reverberation Chambers Located at NSWC, Dahlgren, Virginia," NBSIR 86-3051 (June 1986).]

This paper describes measurement procedures and results obtained from evaluating the reverberating chamber facility located at the Naval Surface Weapons Center (NSWC), Dahlgren, Virginia. The facility was developed by the NSWC for use in measuring and analyzing the electromagnetic susceptibility/vulnerability (EMS/V) of weapon systems and the shielding effectiveness of enclosures and shielding materials. A brief description of the facility is given including the instrumentation used for performing the evaluation and calibration of the facility and for its use in performing EMS/V tests. Measurements described include the chamber's: (1) insertion loss of coupling efficiency, (2) tuner(s) effectiveness, and (3) test zone E-field uniformity and absolute amplitude calibration. Advantages and limitation for use of the reverberating chamber method are summarized along with comments on interpreting measurement results and on conclusions derived from these studies.
[Contact: Myron L. Crawford, (303) 497-5497]

Crawford, M.L., and Koepke, G.H., **Performing EM Susceptibility/Vulnerability Measurements Using a Reverberation Chamber**, Proceedings of the 7th International Symposium and Technical Exhibition on EMC, Zurich, Switzerland, March 3-5, 1987, pp. 121-126 (1987).

This paper discusses the design, evaluation, and use of a reverberation chamber for performing electromagnetic susceptibility (EMS) measurements of electronic equipment. Included are brief descriptions of the test procedures, application advantages and limitations, some EMS test results, interpretation of test results relative to free-space test methods, and an estimate of measurement uncertainties.
[Contact: Myron L. Crawford, (303) 497-5497]

Francis, M.H., and Hill, D.A., **Out-of-Band Response of Array Antennas**, Proceedings of the 9th Annual Meeting and Symposium of the Antenna Measurement Technique Association (AMTA), Seattle, Washington, September 28-October 2, 1987, pp. 14-19 (1987).

At the National Bureau of Standards, we have examined the out-of-band response of array antennas from both a theoretical and experimental point of view. Theory shows that the out-of-band response of an antenna depends primarily on two factors: the antenna's input

Radiated EMI (cont'd.)

impedance and its directivity. Experiment shows that, for most practical purposes, the out-of-band response of an antenna can be estimated from a measurement of the antenna's input reflection coefficient alone. If the reflection coefficient is low, the antenna response will be good; if the reflection coefficient is high, the antenna response will be poor.
[Contact: Michael H. Francis, (303) 497-5873]

Hill, D.A., and Cavcey, K.H., **Coupling Between Two Antennas Separated by a Planar Interface**, IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-25, No. 4, pp. 422-431 (July 1987).

The plane-wave spectrum technique is used to analyze the coupling between a pair of antennas separated by a planar interface. Multiple reflections between the antennas or between either antenna and the interface are included in the formulation. The formulation is used for model detection of buried objects, and a low-frequency metal detector example is analyzed in detail. For a transmitting loop and a buried oblate spheroid, the plane-wave spectrum technique is shown to agree with well-known quasi-static approximations. Some experimental results from a 3-kHz metal detector are also shown.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., and Francis, M.H., **Out-of-Band Response of Antenna Arrays**, Proceedings of the 1987 IEEE International Symposium on Electromagnetic Compatibility, Symposium Record, August 25-27, 1987, Atlanta, Georgia, pp. 435-438 (1987). [An expanded version appeared as NBSIR 86-2037 (June 1986).]

The response of antenna arrays to out-of-band frequencies has been analyzed using the effective aperture approach. An average value of effective aperture can be obtained by averaging the incidence angle and the polarization of the incident field. Far-field patterns have also been calculated by treating the array element excitations as random variables. The randomness in the element excitations causes a decrease in directivity and an increase in sidelobe level.
[Contact: David A. Hill, (303) 497-3472]

Jesch, R.L., **Measurement of Shielding Effectiveness of Different Cable and Shielding Configurations by Mode-Stirred Techniques**, NBSIR 87-3076 (October 1987).

The shielding effectiveness of cable configurations having different shielding arrangements and of shielding configurations used to terminate cable shields for helicopter wiring was measured by mode-stirred techniques. The mode-stirred measurements were taken at discrete frequencies between 200 MHz and 6 GHz. In addition, shielding effectiveness data on the shielding configurations were also obtained in a transverse electromagenetic cell down to 1 MHz. A description of the cable and shielding configurations is given along with plots of the measured shielding effectiveness data as a function of frequency.
[Contact: Ramon L. Jesch, (303) 497-3496]

Kanda, M., and Orr, R.D., **Near-Field Gain of a Horn and an Open-Ended Waveguide: Comparison Between Theory and Experiment**, IEEE Transactions on Antennas and Propagation, Vol. AP-35, No. 1, pp. 33-40 (January 1987). [Also appeared in Symposium Digest, proceedings of the AP-S International Symposium 1986, Vol. I, pp. 91-94 (June 8-13, 1986) and in the Proceedings of the Fifth International Conference on Electromagnetic Compatibility, University of York, United Kingdom, September 29-October 2, 1986, pp. 137-145.]

Radiated EMI (cont'd.)

Generating a standard electromagnetic field requires knowledge of the gain of the transmitting antenna. The theory and supporting experimental measurements for the near-field gain of a pyramidal horn and an open-ended waveguide (OEG) at 450 MHz are given. The empirical near-field gain for the OEG is derived from experimental results obtained by a two-antenna method at about 2 GHz. The theoretical near-field gain for the rectangular pyramidal horn is derived from Schelkunoff's formula. Two independent near-field gain measurements of these antennas are made using a three-antenna method and a transfer-standard-probe method. The discrepancy between theoretical and experimental results is typically less than ±1 dB.
[Contact: Motohisa Kanda, (303) 497-5320]

Koepke, G.H., Hill, D.A., and Ma, M.T., **Analysis of an Array of Log-Periodic Dipole Antennas for Generating Test Fields**, NBSIR 87-3068 (June 1987).

An analysis of log-periodic dipole antennas was extended to study their use in arrays designed for electromagnetic susceptibility measurements. Parameters of an array of five log-periodic dipole antennas were calculated and in some cases compared to a single log-periodic dipole antenna. These parameters were used to evaluate the tradeoffs that exist in the design of an optimum transmitting antenna for susceptibility measurements.
[Contact: Galen H. Koepke, (303) 497-5766]

Ma, M.T., and Bensema, W.D., **Automated TEM Cell for Measuring Unintentional EM Emissions**, Proceedings of the 1987 International Conference on Electromagnetic Compatibility (EMC EXPO), San Diego, California, May 19-21, 1987, pp. T11.1-T11.12 (1987).

This paper summarizes the basic electrical properties of a transverse electromagnetic (TEM) cell, and the underlying theoretical background, based on which a TEM cell is used to measure accurately the emission of an unknown, unintentional leakage source. The theory and measurements have been verified by the results of a simulated example and two experiments using a spherical dipole radiator and a small loop antenna. Recent development of an automated measurement system is also discussed.
[Contact: Mark T. Ma, (303) 497-3800]

Randa, J.P., and Kanda, M., **A New Approach to Volumes Irradiated by Unknown Sources**, IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-29, No. 4, pp. 273-281 (November 1987).

We suggest an approach to the characterization of electromagnetic environments irradiated by unknown sources. The approach is based on the numerical solution of Maxwell's equations subject to the constraints imposed by the measured values of the field at a small number of measurement points and by boundary conditions. A thorough examination of a method for the numerical solution is presented. The examples attempted demonstrate the approach but reveal deficiencies in the numerical method. Possible future directions are suggested.
[Contact: James P. Randa, (303) 497-3150]

Wilson, P.F., and Ma, M.T., **Techniques for Measuring the Shielding Effectiveness of Materials**, Proceedings of the 7th International Symposium and Technical Exhibition on EMC, Zurich, Switzerland, March 3-5, 1987, pp. 547-552. [A more complete version appeared as NBS Technical Note 1095 (May 1986).]

Four methods for measuring the shielding effectiveness of materials under various conditions are considered. Coaxial transmission line holders and a time-domain system are used to simulate plane-wave shielding performance. The

Radiated EMI (cont'd.)

dual (TEM) cell and an apertured TEM cell in a reverberating chamber are used to investigate near-field shielding capability. Both theoretical and experimental results are discussed.
[Contact: Perry F. Wilson, (303) 497-3842]

Wu, D.I., and Chang, D.C., **An Investigation of a Ray-Mode Representation of the Green's Function in a Rectangular Cavity**, NBS Technical Note 1312 (September 1987).

In a rectangular cavity, it is well known that a point source-excited field can be represented either in terms of summation of modes or in terms of rays produced by the equivalent image sources. Both representations involve series that are slowly convergent, so computation of fields inside the cavity is difficult. To obtain a numerically efficient scheme, a hybrid ray-mode representation is developed here using the finite Poisson summation formula. The modal representation is modified in such a way that all the modes near resonance are retained while the truncated remainder of the mode series is expressed in terms of a weighted contribution of rays. For a large cavity, the contribution of rays from far away images becomes small; therefore, the ray sum can be approximated by one or two dominant terms without a loss of numerical accuracy. To illustrate the accuracy and the computational simplification of this ray-mode representation, numerical examples are included with the conventional mode series (summed at the expense of long computation time) serving as a reference.
[Contact: Doris I. Wu, (303) 497-3842]

**ADDITIONAL INFORMATION**

Lists of Publications

Gibson, K.A., Page, J.M., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications**, NBSIR 85-3040 (February 1986).

This bibliography lists publications of the National Bureau of Standards' Electromagnetic Fields Division for the period from January 1984 through September 1985, with selected earlier publications from the Division's predecessor organizations.
[Contact: Kathryn A. Gibson, (303) 497-3132]

Kline, K.E., and DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications**, NBSIR 87-3074 (June 1987).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1986. A few earlier references that are directly related to the present work of the Division are included.
[Contact: Sarabeth Moynihan, (303) 497-3678]

Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division Publications, NBS List of Publications 94** (January 1988).

This bibliography covers publications of the Electrosystems Division, Center for Electronics and Electrical Engineering, NBS, and of its predecessor sections for the period January 1963 to January 1988. A brief description of the Division's technical program is given in the introduction.
[Contact: Jenny C. Palla, (301) 975-2220]

Walters, E.J., **Semiconductor Measurement Technology, NBS List of Publications 72,** [a bibliography of NBS publications for the years 1962-1987] (March 1988).

This bibliography contains reports of work performed at the National Bureau of

Lists of Publications (cont'd.)

Standards in the field of Semiconductor Measurement Technology in the period from 1962 through December 1987. An index by topic area and a list of authors are provided. [Contact: E. Jane Walters, (301) 975-2050]

**1988 CEEE Calendar**

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**VLSI and GaAs Chip Packaging Workshop.** This Workshop is co-sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE and NBS; attendees are expected to be knowledgeable in the field and to participate in discussions. Topic areas include: VLSI and wafer-scale package design (characterization and implementation, cost and performance-driven solutions); package thermal design (characteristics, results, and issues); package interconnection options (wire bonding, TAB, flip chip, or optical); GaAs IC packaging (high-speed packaging considerations); package electrical issues (reduction of parasitics, improvements in electrical performance, reduction in line resistance); integrating package design (from die to system, including assembly and test issues); VLSI package materials advancements; die-attach solutions for large chips; and new failure mechanisms in VLSI packaging. [Contact: George G. Harman, (301) 975-2097]

Planned

Early fall (Boulder, CO)

**Fiber Optics Symposium.** [Contact: Aaron A. Sanders, (303) 497-5341]

Late fall (Boulder, CO)

**Symposium on Optical Materials for High Power Lasers** (20th Boulder Damage Symposium). [Contact: Aaron A. Sanders, (303) 497-5341]

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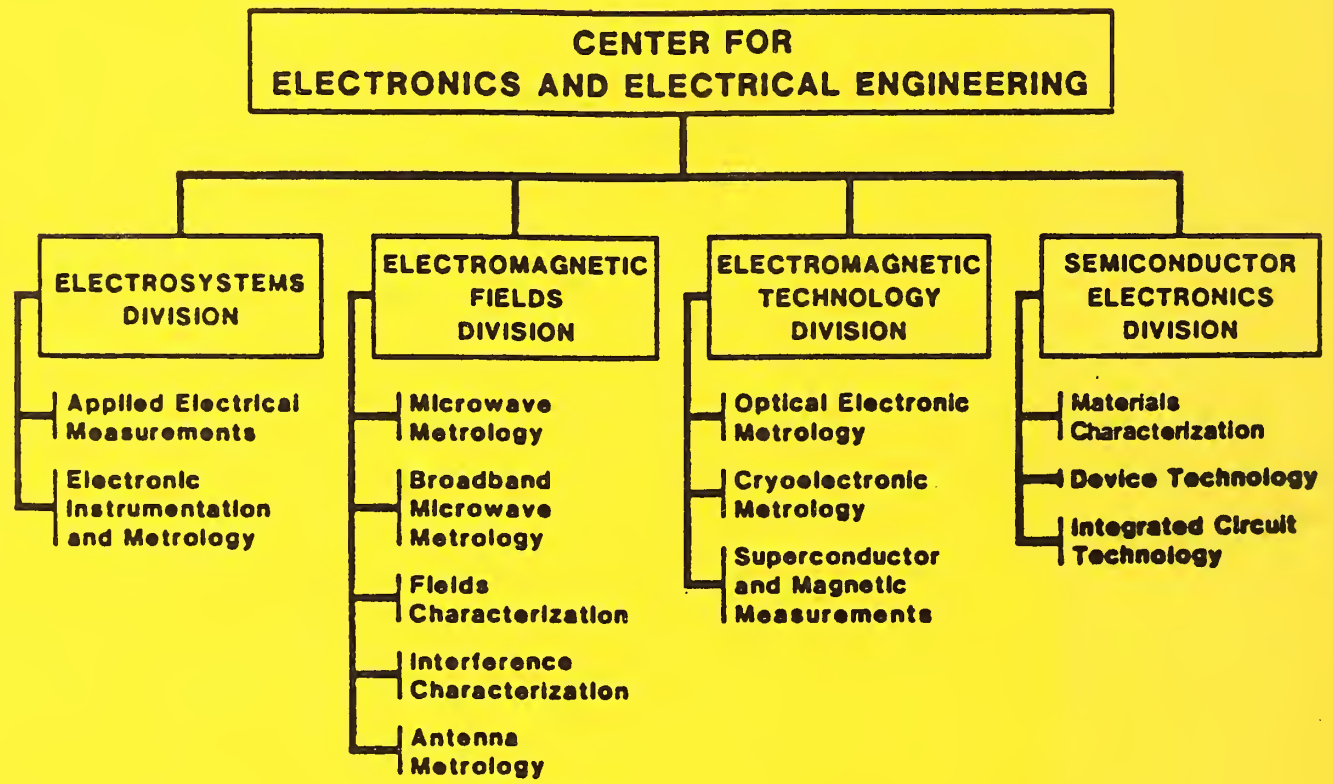


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